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STATUS OF THE LAKE BAIKAL EXPERIMENT

THE BAIKAL COLLABORATION:

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We review the present status of the Baikal Underwater Neutrino Experiment and report on neutrino events recorded with the detector stages *NT-36* and *NT-96*.

1 Detector and Site

The Baikal Neutrino Telescope is being deployed in Lake Baikal, Siberia, 3.6 km from shore at a depth of 1.1 km. At this depth, the maximum light absorbtion length 470 and 500 nm is about 20 m. Scattering is strongly forward peaked ($\langle \cos\theta \rangle \approx 0.95$), with a scattering length about 15 m.

NT-200, the medium-term goal of the collaboration [1], will be finished in April 1998 and consists of 192 optical modules (OMs) – see fig.1. An umbrella-like frame carries 8 strings, each with 24 pairwise arranged OMs. Three underwater electrical cables connect the detector with the shore station. Deployment of all detector components is carried out during 5–7 weeks in late winter when the lake is covered by thick ice.

In April 1993, the first part of *NT-200*, the detector *NT-36* with 36 OMs at 3 strings, was put into operation and took data up to March 1995. A 72-OM array, *NT-72*, run in 1995-96. In 1996 it was replaced by the four-string array *NT-96*. Summed over 700 days effective life time, $3.2 \cdot 10^8$ muon events have been collected with *NT-36, -72, -96*. Since April 6, 1997, *NT-144*, a six-string array with 144 OMs, is taking data.

The OMs are grouped in pairs along the strings. They contain 37-cm diameter *QUASAR* PMTs which have been developed specially for our project. The two PMTs of a pair are switched in coincidence in order to suppress background from bioluminescence and PMT noise. A pair defines a *channel*.

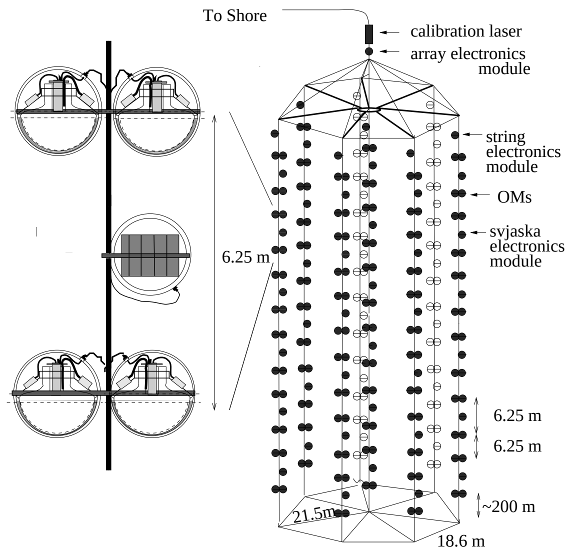

Figure 1: Schematic view of the Baikal Telescope *NT-200*. The modules of *NT-144*, operating since April 1997, are in black. The expansion left-hand shows 2 pairs of optical modules ("svjaska") with the svjaska electronics module, which houses parts of the read-out and control electronics.

A *muon-trigger* is formed by the requirement of $\geq N$ *hits* (with *hit* referring to a channel) within 500 ns. N is typically set to 3 or 4. For such events, amplitude and time of all fired channels are digitized and sent to shore. A separate *monopole trigger* system searches for clusters of sequential hits in individual channels which are characteristic for the passage of slowly moving, bright objects like GUT monopoles.

In the initial project of *NT-200*, the optical modules were directed alternately upward and downward (fig.1). Due to sedimentation of biomatter deterioiating the sensitivity of upward looking OMs we were forced to direct the OMs of the present arrays essentially downward.

2 Separation of Neutrino Events

The signature of neutrino induced events is a muon crossing the detector from below. With the flux of downward muons exceeding that of upward muons from atmospheric neutrino interactions by about 6 orders of magnitude, a careful reconstruction is of prime importance. Two nearly vertical neutrino events have been separated with the rather small *NT-36* [3]. Considering them as atmospheric neutrino events, a 90 % CL upper limit of $1.3 \cdot 10^{-13}$ (muons cm^{-2} sec^{-1}) in a cone with 15 degree half-aperture around the opposite zenith is obtained (threshold energy $E_{th} \approx 6$ GeV) with respect to neutrinos due to neutralino annihilation in the center of the Earth.

In contrast to *NT-36*, *NT-96* can be considered as a real neutrino telescope for a wide region in zenith angle θ. After the reconstruction of all events with ≥ 9 hits at ≥ 3 strings (trigger*9/3*), quality cuts have been applied in order to reject fake events. Furthermore, in order to guarantee a minimum lever arm for track fitting, events with a projection of the most distant channels on the track (Z_{dist}) less than 35 meters have been rejected. Due to the small transversal dimensions of *NT-96*, this cut excludes zenith angles close to the horizon (see fig.2).

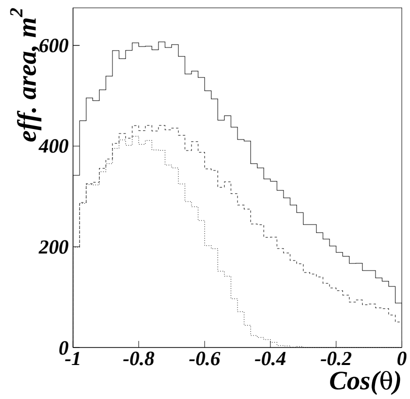

Figure 2: Effective area for upward muons satisfying trigger *9/3*; solid line – no quality cuts; dashed line – final quality cuts; dotted line – final quality cuts and restriction on Z_{dist} (see text).

The efficiency of the procedure has been tested with $1.8 \cdot 10^6$ MC generated atmospheric muons, and with upward muons due to atmospheric neutrinos. It turns out that $S/N > 1$ for the lowest curve in fig.2. The reconstructed angular distribution of $5.3 \cdot 10^6$ events taken with *NT-96* in April/May 1996 – after all cuts – is shown in fig.3

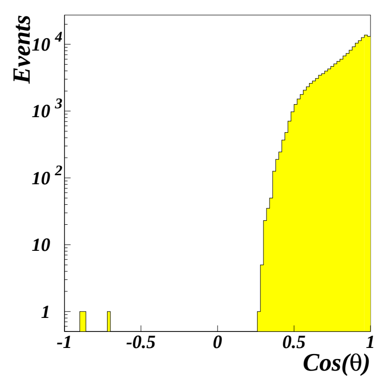

Figure 3: Experimental angular distribution of events satisfying trigger *9/3*, all final quality cuts and the limit on Z_{dist} (see text).

From the first 18 days lifetime, three neutrino candidates have been separated, in good agreement with the expected number of approximately 2.3. Fig.4 displays one of the neutrino candidates. Top right the times of the hit channels are shown as a function of the vertical position of the channel. At each string we observe the time dependence characteristically for upward moving particles. The angle regions $\psi^{min} - \psi^{max}$ consistent with the observed time differences Δt_{ij} between two channels i, j are given by

$$\cos(\psi^{min} + \eta) < \cos\psi \frac{c \cdot \Delta t_{ij}}{\vec{r}_j - \vec{r}_i} < \cos(\psi^{max} - \eta) \qquad (1)$$

with $\vec{r}_i, \vec{r}_j$ being the coordinates of the two channels, ψ the muon angle with respect to $\vec{r}_j - \vec{r}_i$ and η the Cherenkov angle. The bottom right picture of fig.4 shows that the overlap region of all channel combinations of this event clearly lay below horizon. The same holds for the other two events.

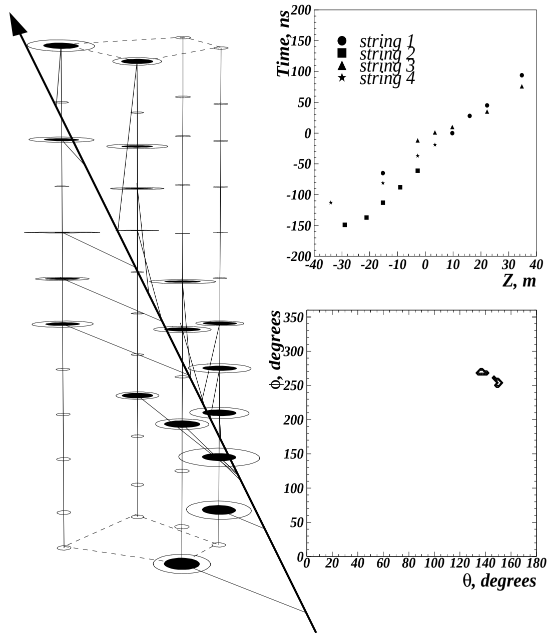

Figure 4: A "gold plated" 19-hit neutrino event. *Left:* Event display. Hit channels are in black. The thick line gives the reconstructed muon path, thin lines pointing to the channels mark the path of the Cherenkov photons as given by the fit to the measured times. The areas of the circles are proportional to the measured amplitudes. *Top right:* Hit times versus vertical channel positions. *Bottom right:* The allowed θ/ϕ regions (see text) The fake probability of this event is smaller than 1%.

In the mean time, altogether 70 days from *NT-96* have been analyzed, and 12 neutrino candidates have been found. Nine of them have been fully reconstructed, 3 nearly upward vertical tracks hit only 2 strings and give a clear zenith angle but ambiguities in the azimuth angle – similar to the two events from *NT-36*. Taking into account the degradation of *NT-96* due to failed OMs, this is in agreement with MC expectations.

3 Outlook

The Baikal detector is well understood, and first atmospheric neutrinos have been identified. Also muon spectra have been measured, and limits on the fluxes of magnetic monopoles as well as of neutrinos from WIMP annihilation in the center of the Earth have been derived.

The *NT-200* detector will be completed in April 1998. In the following years, it will be operated as a neutrino telescope with an effective area between 1000 and 5000 m^2 typically, depending on the energy. It will investigate atmospheric neutrino spectra above 10 GeV (about 1 atmospheric neutrino per day). Presumably still too small to detect neutrinos from AGN and other extraterrestrial sources, *NT-200* can be used to push the flux limits for neutrinos from WIMP annihilation and for magnetic monopoles. It will also be a unique environmental laboratory to study water processes in Lake Baikal.

Apart from its own value, *NT-200* is regarded to be a prototype, for the development a telescope 20-50 times larger. With 2000 OMs, a threshold of 10-20 GeV and an effective area of 50,000 to 100,000 m^2, this telescope would have a realistic detection potential for extraterrestrial sources of high energy neutrinos. With its comparatively low threshold, it would fill a gap between underground detectors and planned high threshold detectors of cube kilometer size.

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3. I.A.Belolaptikov et al., Proc. 25th ICRC 7, (Durban, 1997) 173 (astroph/9705245).